UNIZG-FER 222464

Web Architecture, Protocols, and Services

Web Notification (Web Push) Techniques

Asynchronous Web Protocols and Browser Networking APIs

- XMLHttpRequest (AJAX)
- Server-Sent Events (SSE)
- WebSocket

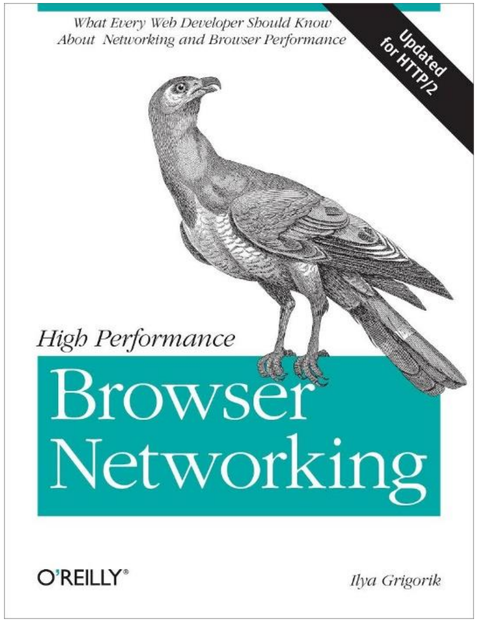
Reading Material

- **High Performance Browser Networking**

  Ilya Grigorik

  O'Reilly Media, September 2013 (total pages: 383)

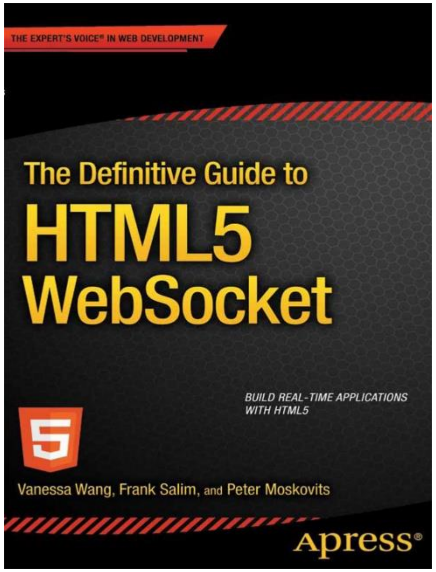
  Relevant content: **Part IV: Browser APIs and Protocols**



- **The Definitive Guide to HTML5 WebSocket**

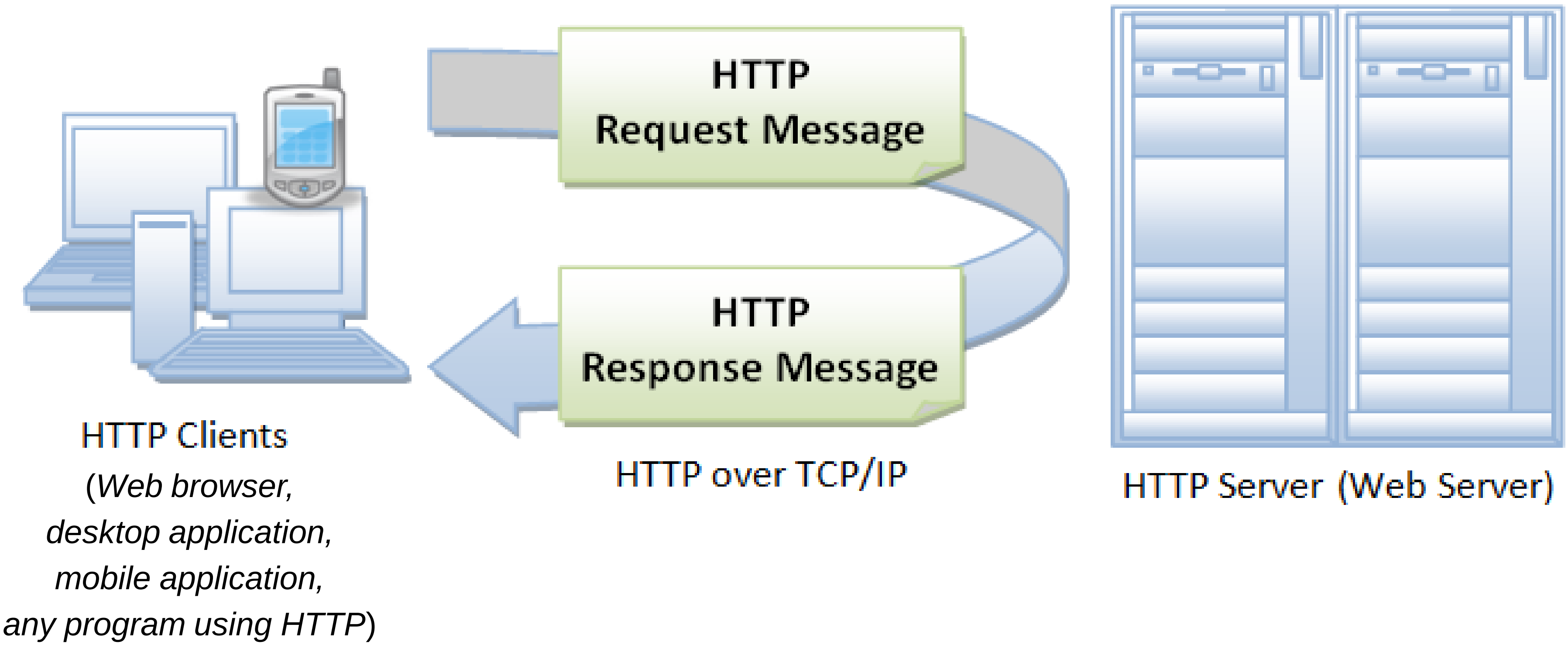
  Vanessa Wang, Frank Salim, Peter Moskovits

  Apress, 2013 (total pages: 188)



HTTP Limitations

- Synchronous protocol
  - Strictly follows the request-response communication pattern
    - Server never sends data to the client without explicitly being asked for that data by the client



HTTP Limitations

- Satisfactory for applications the protocol was initially designed for

- Modern web applications require communication patterns HTTP protocol lacks the support for
  - Asynchronous data transfers
    - Examples: sensory readings
      stock exchange monitoring
      live sports results
  - Data streams
    - Continuous data delivery

Real-time notification

- TCP/IP connection
  - Bidirectional and asynchronous
- HTTP over TCP/IP
  - ***Artificially*** limited to bidirectional, but synchronous mode

Web Application Development Limitations

- Plain old web browser
  - Web application developer has little or no control over how and when an HTTP request would be dispatched
  - End user actions
    - **Entering URL in browser's address bar**
    - Clicking an active link
    - Submitting a form

Web Application Development Limita

– End user actions
  - Entering URL in browser's address bar
  - **Clicking an active link**
  - Submitting a form

```
<html>

 <head></head>

 <body>
  <h1>Title</h1>
  <h2>Subtitle</h2>
  <p>Text paragraph</p>
  <img src="http://www.c.com/image.gif" />
  <a href="http://www.b.com/page2.html">Another page</a>
  <form method="POST" action="http://api.sms.com/sendsms">
   <input type="text" name="phonenumber" />
   <input type="text" name="msgtext" />
   <input type="submit" />
  </form>
 </body>

</html>
```

Web Application Development Limita

- End user actions
  - Entering URL in browser's address bar
  - Clicking an active link
  - **Submitting a form**

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   <input type="text" name="msgtext" />
   <input type="submit" />
  </form>
 </body>

</html>
```

Web Application Development Limita

- Automatic browser-initiated actions
  - Fetching of embedded subresources

```
<html>

 <head></head>

 <body>
  <h1>Title</h1>
  <h2>Subtitle</h2>
  <p>Text paragraph</p>
  <img src="http://www.c.com/image.gif" />
  <a href="http://www.b.com/page2.html">Another page</a>
  <form method="POST" action="http://api.sms.com/sendsms">
   <input type="text" name="phonenumber" />
   <input type="text" name="msgtext" />
   <input type="submit" />
  </form>
 </body>

</html>
```

Web Application Development Limita

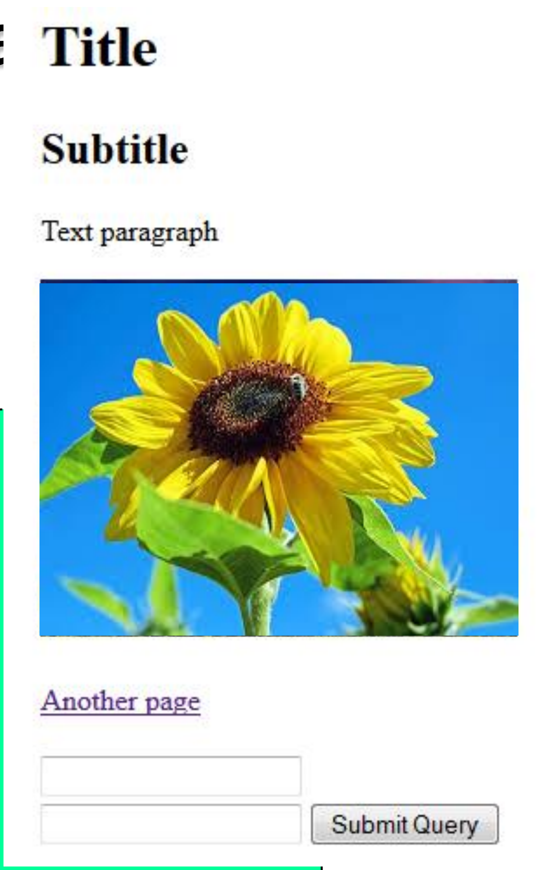
– Limited application-specific control
  - Run-time change of subresource URL
  - Resource gets reloaded from server

```
<html>

 <head></head>

 <body>
  . . . . .
  <img id="myImage"
       src="http://www.c.com/globe.gif" />
  . . . . .
  <script>
    function changeImage() {
      document.getElementById("myImage").src =
                                http://www.c.com/sunflower.jpg
    }
  </script>
 </body>

</html>
```



XMLHttpRequest (XHR)
(Asynchronous JavaScript And XML)

XMLHttpRequest (XHR)

- Browser-level API that enables the client to script data transfers via JavaScript
  - XHR made its first debut in Internet Explorer 5 in 1999
  - One of the key technologies behind the **Asynchronous JavaScript and XML (AJAX)** revolution
  - XHR is now a fundamental building block of nearly every modern web application

- Prior to XHR, the web page had to be refreshed to send or fetch any state updates between the client and server

- With XHR, this workflow could be done asynchronously and under full control of the application JavaScript code

XMLHttpRequest (XHR)

- Common XHR usage pattern

```
var xhr = new XMLHttpRequest();
```

- *instantiates new XHR object to use in web application*

```
xhr.open('GET', '/image.jpg');
```

```
xhr.open('GET', 'http://thirdparty.com/image.jpg');
```

- *initializes new HTTP request*

```
xhr.onload = function() {
  .....
};
```

- *callback function invoked automatically by the browser once the HTTP response from the server has arrived*

```
xhr.send();
```

- *sends HTTP request to the server*

XMLHttpRequest (XHR)

- XHR dynamics

```
xhr.send();
```

HTTP request

```
GET /image.jpg HTTP/1.1
Host: thirdparty.com
```

HTTP response

```
HTTP/1.1 200 OK
Content-Type: image/jpeg
Content-Length: 9876

[image data representation]
```

```
xhr.onload = function() {
  .....
  this.status
  this.response
  .....
};
```

XMLHttpRequest (XHR)

- XHR can transfer both text-based and binary data (*not limited to XML as the name may suggest*)

- The browser offers automatic encoding and decoding for a variety of native data types

Native Data Type	Description
`Text`	A simple text string
`Document`	Parsed HTML or XML document
`JSON`	JavaScript object representing a data structure defined using JSON
`ArrayBuffer`	Fixed-length binary data buffer
`Blob`	Binary large object of immutable data

Example: Downloading Data with XHR

```
var xhr = new XMLHttpRequest();
xhr.open('GET', '/socialdata/friends_online');

/* By default, the browser relies on the HTTP content-type
   negotiation to infer the appropriate data type (e.g.,
   decode an application/js
   Otherwise, the applicati
   data type when initiatin
xhr.responseType = 'json';

xhr.onload = function() {
  if (this.status == 200) {
    for (i=0; i < this.resp
      var friend = document
      friend.innerText = th
      friend.href = this.re
      document.body.appendC
    }
  }
};

xhr.send();
```

HTTP request

```
GET /socialdata/friends_online HTTP/1.1
Host: example.com
```

HTTP response

```
HTTP/1.1 200 OK
Content-Type: application/json
Content-Length: 1234

[
  { "name": "John Smith",
    "profile_page": "http://..." },
  .....
  .....
]
```

Example: Uploading Data with XHR

```
/* Uploading simple textual data */
var xhr = new XMLHttpRequest();
xhr.open('POST', '/upload');
xhr.onload = function() { ... };
xhr.send('This is my text.');
```

HTTP request

```
POST /upload HTTP/1.1
Host: example.com
Content-Type: text/plain
Content-Length: 16

This is my text.
```

```
/* Uploading form data */
var formData = new FormData();
formData.append('id', 123456);
formData.append('topic', 'performance');
var xhr = new XMLHttpRequest();
xhr.open('POST', '/upload');
xhr.onload = function() { ... };
xhr.send(formData);
```

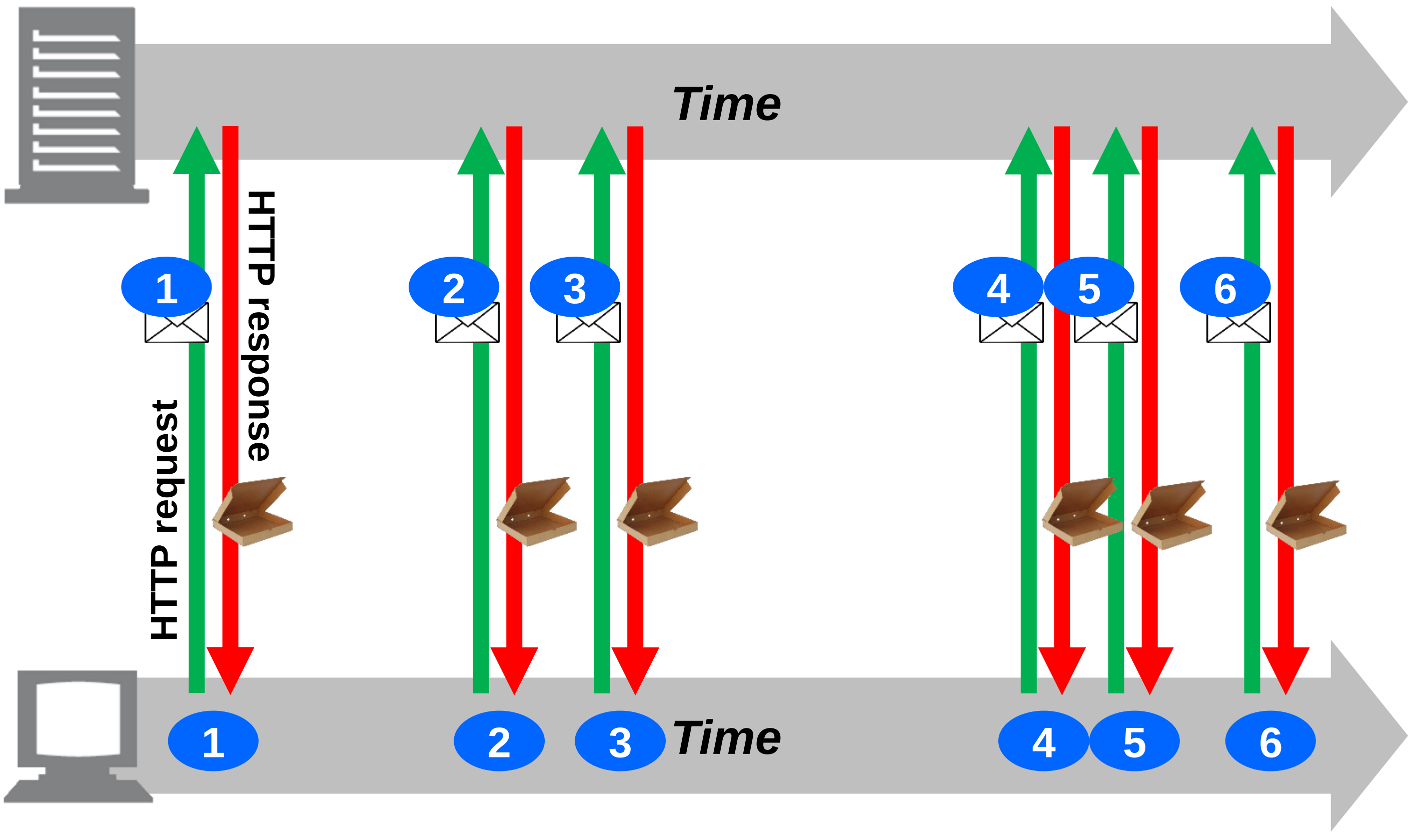
HTTP request

```
POST /upload HTTP/1.1
Host: example.com
Content-Type: application/x-www-form-urlencoded
Content-Length: 27

id=123456&topic=performance
```

Real-Time Notifications on the Web

- Client-To-Server notifications
  - How to synchronize client updates with the server?
  - Client sends an HTTP request with notification data in message body
  - Server responds with empty HTTP response (headers only, no body)



Real-Time Notifications on the Web

- Client-To-Server notifications
  - Implementation using *XMLHttpRequest*
  - Each notification is implemented as a separate **XHR upload pattern**

```
var xhr = new XMLHttpRequest();

xhr.open('POST', '/update');

xhr.onload = function() {
  if (this.status != 200 and this.status != 204) {
    document.body.write('Update operation failed');
  }
};

xhr.send(data);
```

Real-Time Notifications on the Web

- Client-To-Server notifications

Example

- Size of notification payload data: 10 bytes
- Typical size of HTTP request header: cca. 500 bytes
- Typical size of HTTP response header: cca. 500 bytes

$$\boldsymbol{efficiency\ of\ communication} =$$

$$= \frac{size\ of\ payload\ data}{HTTP\ request\ size + HTTP\ response\ size}$$

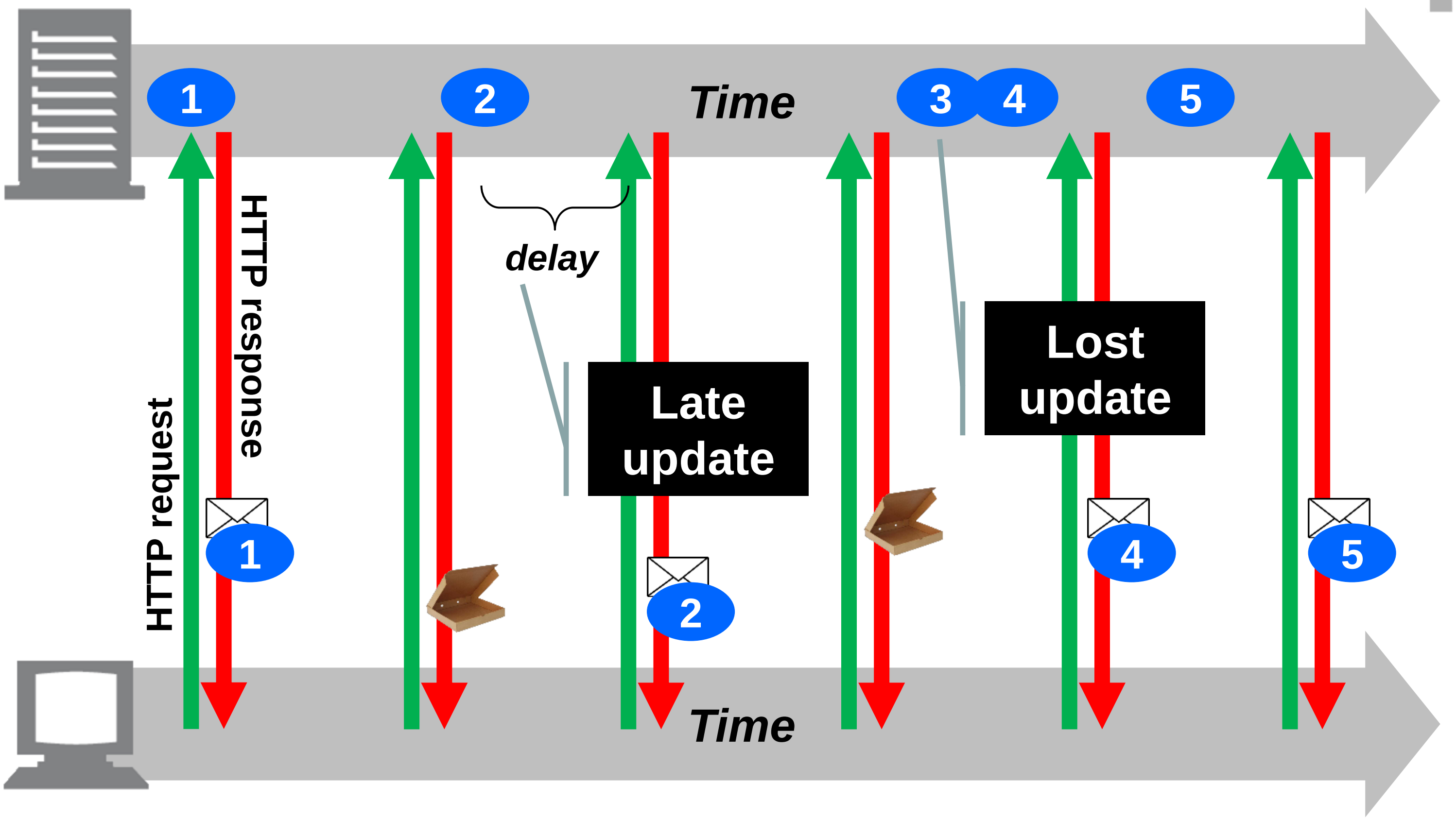
$$= \frac{payload\ size}{request\ header\ size + request\ body\ size + response\ header\ size}$$

$$= \frac{payload\ size}{request\ header\ size + payload\ size + response\ header\ size}$$

$$= \frac{\mathbf{10}}{\mathbf{500 + 10 + 500}} \approx \mathbf{1}\%$$

Real-Time Notifications on the Web

- Server-To-Client notifications
  - How to synchronize server updates with the client(s)?
  - In HTTP, server cannot deliver any data to the client, without being explicitly asked for them
  - Simplest solution: clients need to do periodic checks ⇒ **POLLING**



Real-Time Notifications on the Web

- Server-To-Client notifications
  - Implementation using *XMLHttpRequest*
  - Each notification is implemented as a separate **XHR download pattern, scheduled periodically**

```
function checkUpdates() {
  var xhr = new XMLHttpRequest();

  xhr.open('GET', '/update');

  xhr.onload = function() {
    if (this.status == 200) {
      document.getElementById('update').innerText = this.response;
    }
  };

  xhr.send();
}

setInterval(checkUpdates(), 60000);
```

Real-Time Notifications on the Web

- Server-To-Client notifications

Example

- Size of notification payload data: 10 bytes
- Typical size of HTTP request header: cca. 500 bytes
- Typical size of HTTP response header: cca. 500 bytes
- Maximum allowed notification delay: 5 seconds
- Longest period between two consecutive server updates: 1 hour
- 10,000 clients connected to a server

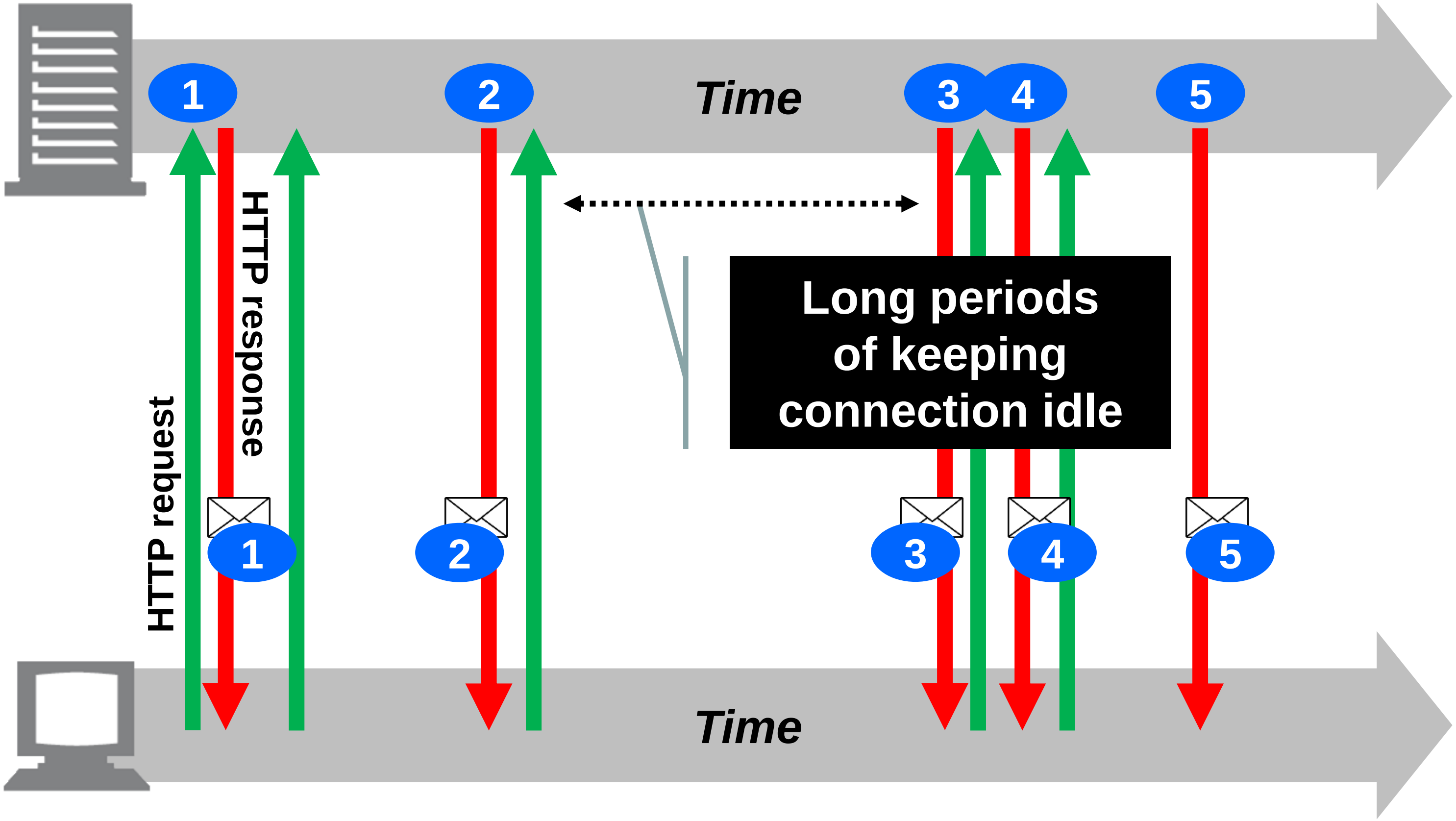
$$\boldsymbol{efficiency\ of\ communication =}$$
$$\boldsymbol{= \frac{10}{719 * (500 + 500) + 1 * (500 + 500 + 10)} \approx 0.0013\%}$$

$$\boldsymbol{ideal\ throughput = \frac{10 * 8}{5} * 10{,}000 = 160\ kbps}$$

$$\boldsymbol{required\ throughput =}$$
$$\boldsymbol{= \frac{(719 * (500 + 500) + 1 * (500 + 500 + 10)) * 8}{3600} * 10{,}000 \approx 16\ Mbps}$$

Real-Time Notifications on the Web

- Server-To-Client notifications
  - Instead of returning empty response, server keeps the connection idle until an update is available ⇒ **LONG POLLING**
  - No delays, but waste of server network resources (TCP connections) is likely to occur (long-lived connections)



Real-Time Notifications on the Web

- Server-To-Client notifications
  - Implementation using *XMLHttpRequest*
  - Each notification is implemented as a separate **XHR download pattern, scheduled immediately upon completion of a previous one**

```
function checkUpdates() {
  var xhr = new XMLHttpRequest();

  xhr.open('GET', '/update');

  xhr.onload = function() {
    if (this.status == 200) {
      document.getElementById('update').innerText = this.response;
    }
    checkUpdates();
  };

  xhr.send();
}
```

Real-Time Notifications on the Web

- Server-To-Client notifications

Example

- Size of notification payload data: 10 bytes
- Typical size of HTTP request header: cca. 500 bytes
- Typical size of HTTP response header: cca. 500 bytes

$$\boldsymbol{efficiency\ of\ communication} =$$

$$= \frac{payload\ size}{request\ header\ size + response\ header\ size + payload\ size}$$

$$= \frac{\mathbf{10}}{\mathbf{500 + 10 + 500}} \approx \mathbf{1}\%$$

- Network load
  - Much more efficient than polling (1 % vs. 0.0013 %)
  - Efficiency compared to XHR-based client-to-server notification
- Server load
  - **Can waste server resources (TCP connections)**

Server-Sent Events (SSE)

Server-Sent Events (SSE)

- Enables efficient **server-to-client** streaming of **text-based** event data

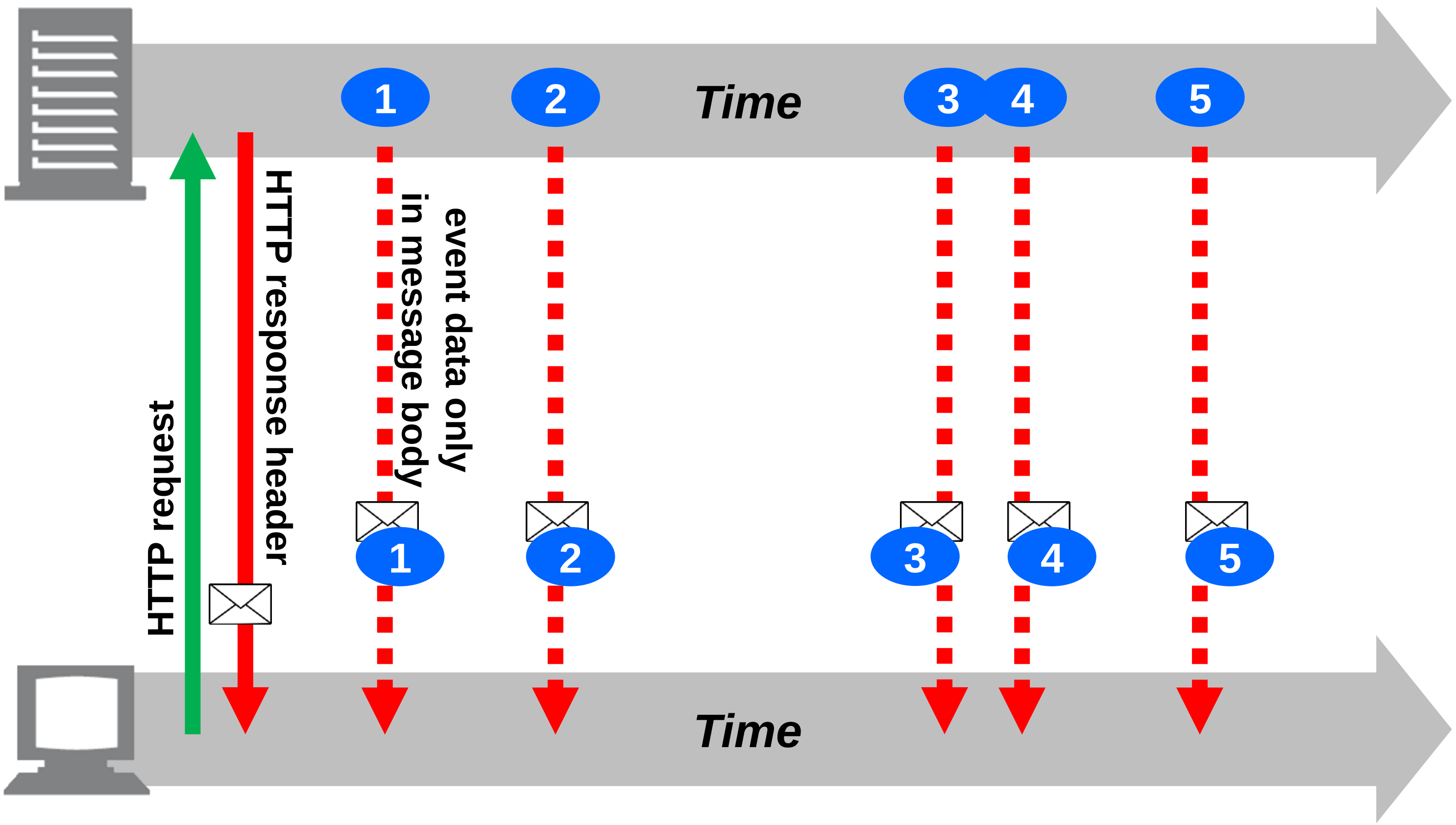
- Introduces two new browser API components

`EventSource`	Interface which allows the client to receive push notifications from the server as DOM events
`event stream`	Data format used to deliver the individual updates

- Characteristics
  - Low latency delivery via a single, long-lived connection
  - Efficient browser message parsing with no unbounded buffers
  - Automatic tracking of last seen message and auto reconnect
  - Client message notifications as DOM events
  - No need for repeated HTTP requests
    - Only one HTTP request is necessary to initialize the event stream

Server-Sent Events (SSE)

- Client initiates the connection through HTTP request
- Server confirms the connection with HTTP response and keeps the connection alive
- Subsequent updates are appended to the message body of the HTTP response



Server-Sent Events (SSE)

- Implementation using *EventSource* API

```
var source = new EventSource("/path/to/stream-url");

source.onopen = function () { ... };

source.onerror = function () { ... };

/* default event handler */
source.onmessage = function (event) {
  log_message(event.id, event.data);
  if (event.id == "CLOSE") {
    source.close();
  }
};

/* event-specific handler */
source.addEventListener("foo", function (event) {
  processFoo(event.data);
});
```

STREAM

Server-Sent Events (SSE)

- `event stream` protocol

HTTP request

```
GET /stream HTTP/1.1
Host: example.com
Accept: text/event-stream
```

HTTP response

```
HTTP/1.1 200 OK
Connection: keep-alive
Content-Type: text/event-stream
Transfer-Encoding: chunked

retry: 15000

data: First message is a simple string.

data: {"message": "JSON payload"}

event: foo
data: Message of type "foo"

id: 42
event: bar
data: Multi-line message of
data: type "bar" and id "42"
```

API

Server-Sent Events (SSE)

- Auto-reconnect
  - If the connection is dropped, `EventSource` will automatically reconnect to the server to resume the event stream
- Tracking of the last seen message
  - `EventSource` will automatically advertise the ID of the last seen message, such that the lost messages can be retransmitted

Stream in progress

```
retry: 15000

id: 42
event: bar
data: Multi-line message of
data: type "bar" and id "42"

id: 43
data: Lorem ipsum
```

connection dropped

....

15 seconds later

HTTP request for reconnection

```
GET /stream HTTP/1.1
Host: example.com
Accept: text/event-stream
Last-Event-ID: 43
```

HTTP response

```
HTTP/1.1 200 OK
Content-Type: text/event-stream
Connection: keep-alive
Transfer-Encoding: chunked

id: 44
data: dolor sit amet
```

Server-Sent Events (SSE)

$$\boldsymbol{efficiency\ of\ communication} = \frac{\sum_{i=1}^{number\ of\ events} event\ size_i}{\begin{matrix} request\ header\ size + \\ response\ header\ size + \\ \sum_{i=1}^{number\ of\ events} event\ size_i \end{matrix}}$$

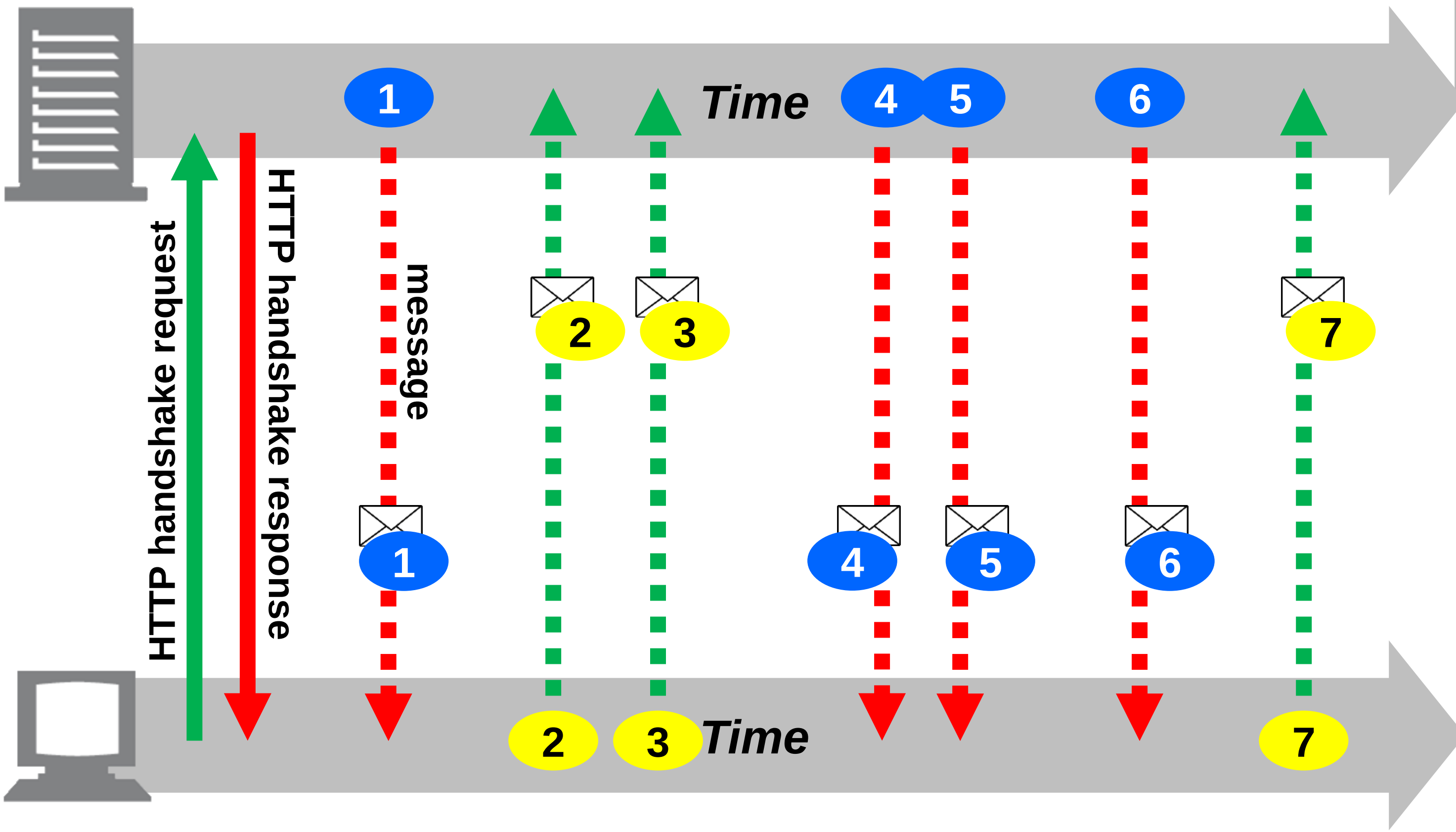
$$\lim_{i \to \infty} \boldsymbol{efficiency\ of\ communication} = \mathbf{1} \Rightarrow \mathbf{100\,\%}$$

- SSE limitations
  - Server-to-client streaming only
  - Limited to text-based UTF-8 encoded data (*other formats should be encoded as base64 string*)

WebSocket

WebSocket

- **Bidirectional**, message-oriented streaming of **text and binary data** between client and server



WebSocket

- The closest API to a raw network socket in the browser
- Browser (or other library) abstracts away all the complexity behind a simple API and provides a number of additional services:
  - Connection negotiation and same-origin policy enforcement
  - Message-oriented communication and efficient message framing
  - Interoperability with existing HTTP infrastructure

`WebSocket protocol`	Network protocol that defines connection management and message framing
`WebSocket API`	Programming interface used by web applications (*web browsers, but other client libraries as well*)

WebSocket API

```
/* Open a new WebSocket connection */
var ws = new WebSocket('ws://example.com/socket');
---------------------------------------------------------------------
/* Optional callback, invoked when the connection is established */
ws.onopen = function () { ... }
---------------------------------------------------------------------
/* Optional callback, invoked when the connection is terminated */
ws.onclose = function () { ... }
---------------------------------------------------------------------
/* Optional callback, invoked if a connection error has occurred */
ws.onerror = function (error) { ... }
---------------------------------------------------------------------
/* A callback function invoked for each new message from the server */
ws.onmessage = function(msg) {
  if (msg.data instanceof Blob) {
    processBlob(msg.data);
  } else {
    processText(msg.data);
  }
}
---------------------------------------------------------------------
/* Client-initiated message to the server */
ws.send("Hello server! This is a text message for you.");
```

WebSocket API

- WebSocket resource URL
  - WebSocket uses its own custom URL scheme (doesn't use `http` or `https`)

`ws`	For plain-text communication (e.g. ws://example.com/socket)
`wss`	For encrypted communication using SSL/TLS (e.g. wss://example.com/socket)

- The primary use case for the WebSocket protocol is to provide an **optimized, bidirectional** communication channel between applications running in the browser and the server

- The WebSocket uses a wire protocol other than HTTP, so the URL scheme is changed to reflect that

WebSocket API

- Sending text and binary data
  - Once a WebSocket connection is established, the client and the server can send and receive text (UTF-8 encoded) and binary messages in both directions over the same TCP connection

```
var ws = new WebSocket('ws://example.com/socket');

ws.onopen = function () {
  /* Sending a text message */
  ws.send("Hello server!");
  ws.send(JSON.stringify({'msg': 'payload'}));

  /* Various ways of sending a binary message.
     Binary options are simply an API convenience: on the wire,
     a WebSocket frame is either marked as binary or text */
  var buffer = new ArrayBuffer(128);
  ws.send(buffer);

  var intview = new Uint32Array(buffer);
  ws.send(intview);

  var blob = new Blob([buffer]);
  ws.send(blob);
}
```

WebSocket API

- Message ordering
  - The `send()` method is asynchronous: the provided data is queued by the client, and the function returns immediately
  - **Do not mistake the fast return for a signal that the data has been sent**
  - All WebSocket messages are delivered in the exact order in which they are queued by the client
  - As a result, a large backlog of queued messages, or even a single large message, will delay delivery of messages queued behind it – **head-of-line blocking**

WebSocket Protocol

- Latest version (v13) defined in RFC 6455 (December 2011)
- Two main components:

`Connection opening handshake`	used to negotiate the parameters of the connection
`Binary message framing mechanism`	allows for low overhead, message-based delivery of both text and binary data

WebSocket Protocol

- Connection opening handshake (*HTTP Upgrade*)
  - Requires one HTTP round trip between client and server
  - HTTP is chosen to stay compatible with the existing web architecture

```
var ws = new WebSocket('ws://thirdparty.com/web-socket');
```

HTTP handshake request

```
GET /web-socket HTTP/1.1
Host: thirdparty.com
Origin: http://example.com
Connection: Upgrade
Upgrade: websocket
Sec-WebSocket-Version: 13
Sec-WebSocket-Key: dGhlIHNhbXBsZSBub25jZQ==
```

HTTP handshake response

```
HTTP/1.1 101 Switching Protocols
Upgrade: websocket
Connection: Upgrade
Access-Control-Allow-Origin: http://example.com
Sec-WebSocket-Accept: s3pPLMBiTxaQ9kYGzzhZRbK+xOo=
```

WebSocket Protocol

- Binary message framing mechanism
  - From this point on, the HTTP-based communication is finished and all further communication is based on *Websocket frames* (binary protocol)

- WebSocket frame
  - `FIN` bit indicates whether the frame is a final fragment of a message. A message may be transfered as a single frame or split into multiple frames
  - `Opcode` indicates type of transferred frame: text (1) or binary (2) for transferring application data; or connection close (8), ping (9), and pong (10) for control frames used for connection liveness checks

<table>
<tr><th>Bit</th><th colspan="3">+0..7</th><th colspan="2">+8..15</th><th>+16..23</th><th>+24..31</th></tr>
<tr><td>0</td><td>FIN</td><td></td><td>Opcode</td><td>Mask</td><td>Length</td><td colspan="2">Extended length (0–8 bytes) ...</td></tr>
<tr><td>32</td><td colspan="7">...</td></tr>
<tr><td>64</td><td colspan="5">...</td><td colspan="2">Masking key (0–4 bytes) ...</td></tr>
<tr><td>96</td><td colspan="5">...</td><td colspan="2">Payload ...</td></tr>
<tr><td>...</td><td colspan="7">...</td></tr>
</table>

WebSocket Protocol

- WebSocket frame
  - `Mask` bit indicates whether the payload is masked (for messages sent from the client to the server only, for intermediaries that do not understand the WebSocket protocol)
  - Payload length is represented as a variable-length field
    - If 0–125, then that is the payload length
    - If 126, then the following 2 bytes represent a 16-bit unsigned integer indicating the payload length
    - If 127, then the following 8 bytes represent a 64-bit unsigned integer indicating the payload length

<table>
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<tr><td>...</td><td colspan="7">...</td></tr>
</table>

WebSocket Protocol

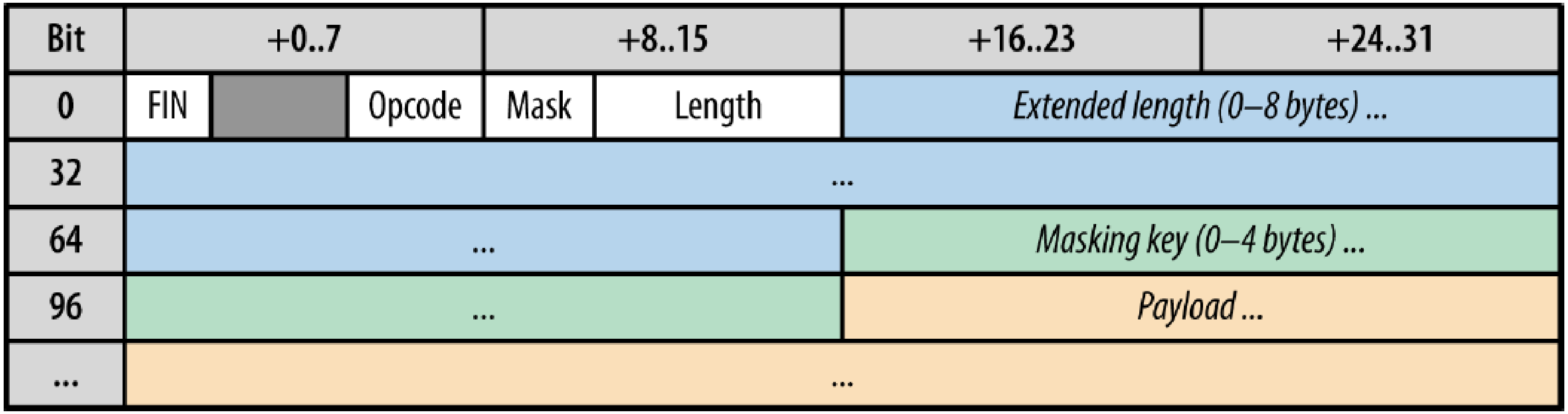
- WebSocket frame
  - `Masking key` contains a 32-bit value used to mask the payload
    - XOR operation is applied to mask 32-bit blocks of payload
  - `Payload` contains the application data

Bit	+0..7			+8..15		+16..23	+24..31
0	FIN		Opcode	Mask	Length	*Extended length (0–8 bytes) ...*	
32	...						
64	...					*Masking key (0–4 bytes) ...*	
96	...					*Payload ...*	
...	...						

WebSocket Protocol

- Framing overhead
  - Due to variable `Length` field, framing overhead is minimized

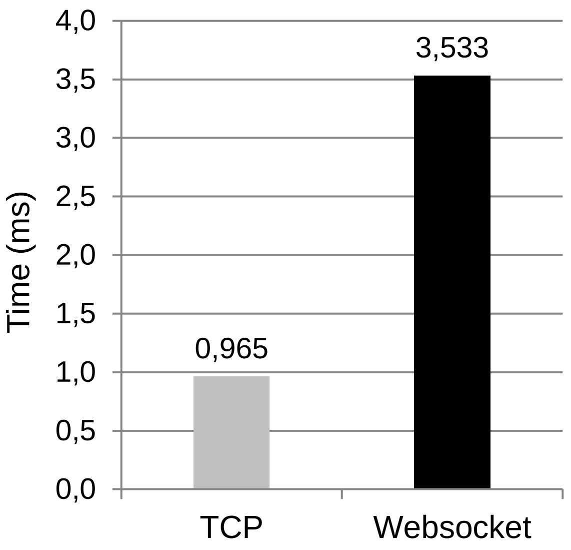
Message length (in bytes)	Client message	Server message
`up to 125`	6	2
`126 to 64k`	8	4
`over 64k`	14	10



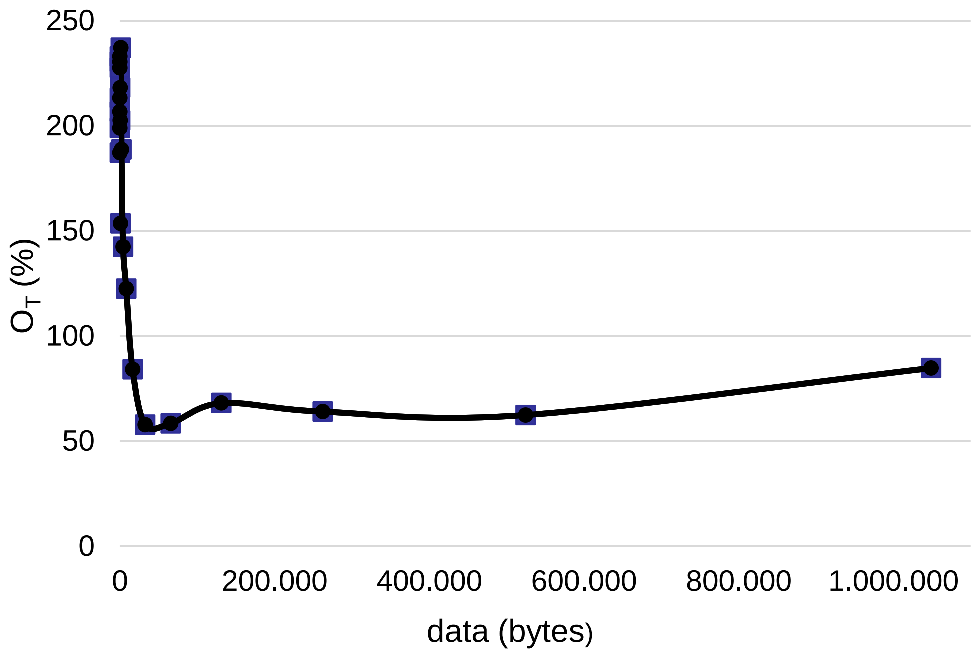
WebSocket Protocol

- Websocket performance related to plain TCP

Connection handshake duration (*HTTP Upgrade*)



Overhead in message transfer duration ($T_{WebSocket}$ / T_{TCP})



Source:
D. Skvorc, M. Horvat, S. Srbljic: **Performance Evaluation of Websocket Protocol for Implementation of Full-Duplex Web Streams**, 37th International Convention on Information and Communication Technology, Electronics and Microelectronics (MIPRO), 2014

Summary of XHR vs. SSE vs. WebSocket

- Each method has its own area of applicability
  - XHR
    - Simple for transactional data transfers (HTTP), not a good choice for data streaming
  - SSE
    - Efficient for streaming, but unidirectional and limited to text-only data
    - Requires long-lived connections
  - WebSocket
    - Most efficient and flexible, but still requires long-lived connections

	XMLHttpRequest	Server-Sent Events	WebSocket
Request streaming	no	no	yes
Response streaming	limited	yes	yes
Framing mechanism	HTTP	event stream	binary framing
Binary data transfers	yes	no (base64)	yes
Compression	yes	yes	limited
Application transport protocol	HTTP	HTTP	WebSocket
Network transport protocol	TCP	TCP	TCP